

Polarized neutron scattering study on antiferromagnetic states in CeRh_{0.6}Co_{0.4}In₅

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Abstract

Polarized neutron scattering experiments were performed on mixed compound CeRh_{0.6}Co_{0.4}In₅ to clarify the nature of the low-temperature ordered states. Three nonequivalent Bragg peaks, characterized by the wave vectors of $q_h \sim (1/2, 1/2, 0.3)$, $q_1 \sim (1/2, 1/2, 0.4)$ and $q_c = (1/2, 1/2, 1/2)$, were observed at 1.4 K. These Bragg peaks are found to occur entirely in spin-flip channel. This indicates that these Bragg peaks originate from the magnetic scattering, *i.e.*, the antiferromagnetic orders with three different modulations appear in this compound.

Key words: quantum critical behavior, CeRhIn₅, CeCoIn₅, magnetism, neutron scattering

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Quantum critical behavior observed in the heavy-fermion compounds has been attracting much interest in recent years. The ternary tetragonal compound CeRhIn₅ shows an incommensurate antiferromagnetic (I-AF) order with the modulation of $q = (1/2, 1/2, 0.297)$ below $T_N = 3.8$ K [1,2]. It is found in the mixed compounds CeRh_{1-x}Co_xIn₅ [3,4] that T_N of the I-AF order is weakly reduced by substituting Co for Rh, and then approaches zero at $x_c \sim 0.7$. At the same time, the superconducting (SC) phase appears above $x = 0.4$. Recently, our elastic neutron scattering experiments revealed that a commensurate antiferromagnetic (C-AF) order with the propagation vector of $q_c = (1/2, 1/2, 1/2)$ as well as the I-AF order with $q_h = (1/2, 1/2, 0.306)$ evolve at $x = 0.4$ [5]. We have also observed weak Bragg peaks characterized by the incommensurate wave vector $q_1 = (1/2, 1/2, 0.403)$, but their origin is still unclear. To clarify the nature of these Bragg peaks, we have performed polarized neutron scattering experiments for CeRh_{0.6}Co_{0.4}In₅.

Single crystals of CeRh_{1-x}Co_xIn₅ with $x = 0.4$ were grown by the In-flux method. To minimize the effects of neutron absorption by Rh and In, we prepared a rod-type sample with the dimensions of $\sim 1.8 \times 1.8 \times 15$ mm³ by

means of a spark erosion. The electron probe microanalysis (EPMA) measurements for the sample indicate that the homogeneous distributions of the elements over the averaged area (~ 1 μ m²) are achieved, but the estimated Co/Rh concentration ($x \sim 0.5$) is slightly larger than the nominal x value (0.4) [6]. Similar deviation of x is also observed in the sample investigated previously [5]. Despite these results, we will use the nominal concentration x throughout this article for simplicity and clarity.

The polarized neutron scattering experiments were carried out on the triple-axis spectrometer ISSP-PONTA (5G) located at the research reactor JRR-3M of the JAEA, Tokai, Japan. The neutron momentum $k = 4.05$ \AA^{-1} was chosen by monochromator and analyzer (Heusler), and a combination of B-80'-80'-B collimators and a pyrolytic graphite (PG) filter was used. The spin direction of the incident neutron beam was tuned to be parallel to the scattering vector Q in Helmholtz coils. In the experimental geometry presently used, it is expected that the nuclear scattering is completely non-spin flip, while any magnetic scattering flips the neutron spins. The polarization ratio of the neutron spins estimated from the nuclear Bragg-peak intensities was ~ 15 . We also performed the unpolarized neutron scattering experiments on the triple-axis spectrometer ISSP-GPTAS (4G). We selected the neutron

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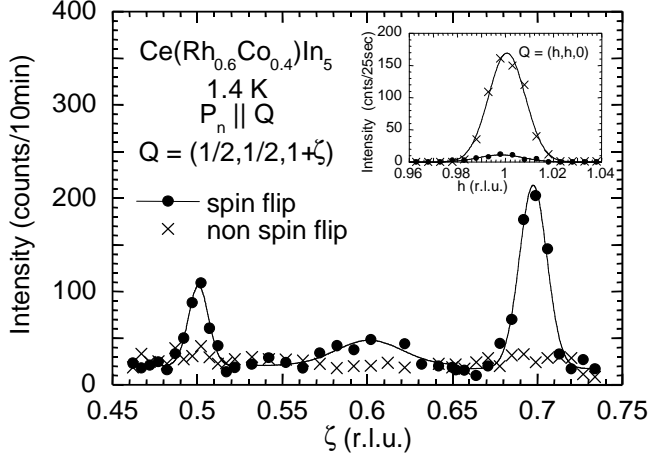


Fig. 1. Neutron scattering patterns in spin-flip and non-spin-flip scattering channels obtained by the scans at $Q = (1/2, 1/2, 1 + \zeta)$ ($0.46 \leq \zeta \leq 0.74$) at 1.4 K for $\text{CeRh}_{0.6}\text{Co}_{0.4}\text{In}_5$. The inset shows the profiles of the (110) nuclear Bragg peak.

momentum $k = 3.79 \text{ \AA}^{-1}$ by PG monochromator and analyzer, and used a 40'-40'-40'-80' collimator and two PG filters. Both the measurements were performed in the (hhl) scattering planes and the temperature range of 1.4–10 K.

Fig. 1 shows neutron scattering patterns in spin-flip (SF) and non-spin-flip (NSF) scattering channels at 1.4 K, obtained from the $Q = (1/2, 1/2, 1 + \zeta)$ ($0.46 \leq \zeta \leq 0.74$) scans in the polarized neutron scattering measurements. The profiles of the (110) nuclear Bragg peak are also displayed in the inset of Fig. 1. We have observed three nonequivalent Bragg peaks at $(1/2, 1/2, 3/2)$, $(1/2, 1/2, 1.60(1))$, and $(1/2, 1/2, 1.697(5))$ in the SF scattering channel, whose positions correspond with those expected from the ordering vectors q_c , q_1 and q_h , respectively. The width of the Bragg peak at $(1/2, 1/2, 1.60)$ is clearly larger than others, indicating that the order with the modulation of q_1 occurs in a shorter range along the c axis. This feature is also observed in our previous measurements [5]. On the other hand, no significant reflection is detected in the NSF scattering channel within the experimental accuracy. These results indicate that all these Bragg peaks originate from the magnetic scattering, *i.e.*, the antiferromagnetic (AF) orders with the modulations of q_c , q_1 and q_h occur at $x \sim 0.4$.

We have estimated the magnitudes of the volume-averaged ordered moments μ_h , μ_1 and μ_c for the AF orders with the modulations of q_h , q_1 and q_c , respectively, from the integrated intensities of the magnetic Bragg peaks obtained by longitudinal and transverse scans with the unpolarized neutron scattering technique. In accordance with the previous reports [2,5,7,8], we assume that both the I-AF orders have the helical AF structures, and the ordered moments in all the AF states lie in the tetragonal basal plane. In Table 1, we show the μ_h , μ_1 and μ_c values at 1.4 K for the sample (labeled as #2) presently investigated, together with those for previous one (#1) [5]. The μ_c/μ_h and μ_1/μ_h values for #2 are found to be significantly smaller

Table 1

The volume-averaged ordered moments of the AF orders with the modulations of q_h , q_1 and q_c at 1.4 K for $\text{CeRh}_{0.6}\text{Co}_{0.4}\text{In}_5$. μ_T indicates the total moment defined by $\mu_T = \sqrt{\mu_h^2 + \mu_1^2 + \mu_c^2}$.

sample	$\mu_h(\mu_B)$	$\mu_1(\mu_B)$	$\mu_c(\mu_B)$	μ_1/μ_h	μ_c/μ_h	$\mu_T(\mu_B)$
#1	0.38(3)	0.17(2)	0.21(2)	0.45(2)	0.55(1)	0.47(5)
#2	0.41(2)	0.15(2)	0.18(1)	0.37(2)	0.44(1)	0.47(4)

than those for #1, while the total moments for #1 and #2 defined by $\sqrt{\mu_h^2 + \mu_1^2 + \mu_c^2}$ are in good agreement with each other. This suggests that the fraction of the moment distributed to each AF state is very sensitive to the sample conditions, such as Co concentration and crystal quality. We consider that the I-AF order with q_1 is generated in parts of the sample because of the large AF Bragg-peak width. However, it is not clear in the present stage whether the AF states with q_h and q_c are microscopically coexistent or inhomogeneously separated. This issue may be resolved by performing NMR and μSR experiments in the future.

We have observed new AF states with the modulations of q_c and q_1 as well as the I-AF state with q_h in $\text{CeRh}_{0.6}\text{Co}_{0.4}\text{In}_5$. The evolution of the C-AF state near the superconducting phase is also found in recent neutron scattering experiments for Ir-doped CeRhIn_5 [9], Cd-doped CeCoIn_5 [10], and NQR experiments for pure CeRhIn_5 under pressure [11], implying that the C-AF correlation plays a key role in the stability of the SC phase in the CeMIn_5 systems ($M=\text{Co, Rh and Ir}$). In addition, the I-AF order with the modulation of $\sim q_1$ is also detected by the high-pressure neutron scattering measurements for pure CeRhIn_5 [8]. The evolutions of the AF states with a variety of the c -axis modulations may be attributed to two dimensional characteristics of these compounds.

In summary, our polarized neutron scattering experiments on $\text{CeRh}_{0.6}\text{Co}_{0.4}\text{In}_5$ revealed that all of the Bragg-peaks associated with the incommensurate (q_h and q_1) and commensurate (q_c) structures occur entirely due to the magnetic scattering. This indicates that the AF orders with three different modulations appear at $x \sim 0.4$.

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